Stock ownership decisions in DC pension plans

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Abstract

This paper considers the risk of employee pension accounts when there is a large weighting in company stock. The effect of reduced diversification and job related risk are considered. Mean-variance and scenario-based stochastic programming models are used for analysis. The stochastic porgramming formulation allows for fat tailed return distributions. Company stock is only optimal for employees with very low risk aversion or with very high return expectations for company stock. These conclusions are further strengthened when the possibility of job loss associated with poor company stock performance is included in the model. High observed weightings in company stock in DC pension plans are not explained by rational one-period models. Employees are bearing high levels of risk that is not rewarded, and that can lead to disastrous consequences.

Keywords: Asset allocation, Defined contribution pension plans, stochastic programming

Preliminary and incomplete version. Comments and suggestions welcome.

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Introduction

Enron corporation collapsed in late 2001. The stock price fell 99% to under one dollar. Many employees lost their jobs and much of their pensions. Enron employees lost over a billion dollars in total, some 60% of their 401(k) pensions. Enron's collapse was a stark illustration of the potential consequences of holding one's pension fund largely in one asset, especially when that asset is correlated with one's income.

The plight of employees following Enron's spectacular collapse has focused attention on portfolio choices of individual investors. Enron sponsored a defined contribution (DC) pension plan. Under the rules of such plans, individual employees make their own investment decisions. Thus, Enron employees had placed themselves in the risky position that cost them so dearly. With large holdings in own company stock, Enron employees accepted excess exposure, relative to the market, to idiosyncratic risk of their employer's stock. Enron is no isolated case. Many DC plans are heavily overweighted in company stock (Table I). For example, in November 2001, employees at Proctor and Gamble had 94.7% of their 401(k) assets in company shares.

Why would investors choose a large weighting in the stock of the company at which they are employed? The apparent overinvestment is puzzling when considered with respect to portfolio choice decisions predicted by the Markowitz mean-variance model. Employees appear to be taking on greater risk than necessary by concentrating ownership in company stock. This behaviour is rendered even more puzzling when contrasted with results of surveys of investor behaviour. Generally, these studies conclude that a large part of the population does not invest in stocks [Mankiw and Zeldes, 1991]. Thus, most investors appear to take on less risk than would be predicted by mean-variance portfolio choice models. Not only do employees take on more risk than predicted by mean-variance theory, they take on more risk than typical individual investors.

The risk associated with holding company stock is great. Three major risk factors limit the weight of company stock in portfolio choice models. First, return properties of own-company stock are often unfavourable when compared to a market index. The volatility of individual stocks is two to three time that of the market. Under the assumptions of the Capital Asset Pricing Model, any excess return of company stock over the market portfolio only compensates for the non-idiosyncratic portion of the stock volatility. Any remaining risk is eliminated by diversification within the market portfolio. Thus, an optimizing investor that is not faced with trading constraints will not hold company stock beyond that included in their optimal market holding. Second, individual stocks can crash. It is not uncommon for companies that enter bankruptcy to lose over 90% of their value in a few months. Small though it is, this "torpedo" risk can significantly decrease the optimal holding of own-company stock. For example, United Airlines (UAL Corp.) stock dropped through ten dollars in July 2002, and slid past one dollar in early December as the company filed for bankruptcy protection. Third, employees' wages are affected by company performance, thereby magnifying the risk of company stock ownership. An employee faces increased risk of lower bonuses, reduced return on stock options and even layoff during periods of poor company performance. The employee can be viewed as being in a long term relationship (employment) with a counterparty who may default (by terminating employment). Loss of wealth following termination has two main causes. First, an employee may lose income over some period of time. This loss depends on the outside market for his services and the length of any severance package. Second, termination following bankruptcy is likely to reduce the value of an employee's future income stream. If one assumes that employees remain at an organization because they have no better, higher utility choice in the market, the loss of that job will negatively effect the value of their expected future utility.

Despite the risk of the strategy, it is possible for company stock to be a rational portfolio choice for pension plan investors. DC pension plans are usually structured such that the investor chooses between a small number of investment options. Short selling of assets within DC plans is not permitted, and hedging outside the plan is usually not feasible due to transaction costs and difficulty of replicating plan assets. The cost to an employee of acquiring the expertise to hedge is usually enough to deter such activity. Given these constraints, company stock can become a favored option for a less risk averse investor. In addition, employees may have higher expectation for the return of company stock than the market.

We investigate employee investment decisions predicted by rational models of portfolio choice. We postulate a representative investment scenario, and consider portfolio choice under various parameter specifications. We investigate the problem using two models of portfolio choice: the Markowitz mean-variance approach (1952), and a scenario based, stochastic programming formulation. The mean-variance approach permits exploration of optimal portfolio choice under the assumption of normally distributed returns. Using the stochastic programming approach, we are able to explore portfolio decisions when the normality assumption is violated, such as when we include a reasonable probability of a disastrous outcome for company stock. We are also able to include job risk as a function of company stock performance. Portfolio choice models include non-observable parameters such as investor risk aversion and return expectations of investors. We avoid the problem of specifying these parameters by considering portfolio choice over a range of parameter space.

Our results demonstrate that the short selling constraint is not sufficient to overcome the additional risk associated with owning company stock. High company stock weightings such as those listed in Table I can only be explained by some combination of implausibly low risk aversion or high return expectations for company stock. These results hold with or without including extreme events. The inclusion of labour income risk in the models further reduces the optimal holding in company stock. In a related paper, Meulbroek (2002) calculates the cost to employees of foregone diversification. However, she compares employee portfolio choices to those of an unconstrained investor. As such, her estimates are an upper bound on cost, and do not themselves demonstrate that observed overinvestment in company stock is costly.

In section I, we introduce the investment scenario, and consider the investor problem in the static mean variance framework. In section II, we formulate the investment problem as a stochastic program. This model provides for more flexibility in choosing distributions of random variables, and setting policy, legal and other constraints. We can model expected losses to human capital as a function of company stock performance.

1 Static portfolio choice

The portfolio allocation problem for a utility maximizing investor is to select holdings that maximize expected lifetime utility

$$\max_{x \in K} \quad E_\xi[U(W)],$$

where K is a convex set. The x are portfolio weights, W is wealth and U is an increasing, concave utility function. To simplify the problem, we assume normal returns, thereby permitting the use of mean-variance utility, $U(W) = E(W) - R_A/2 \times \mathrm{var}(W)$, where R_A is the investor's Arrow-Pratt risk aversion index. In addition to the wealth constraint, short selling is not permitted, since most DC plans do not permit this activity. To simplify the analysis, the employee's problem is considered in a one period context. Since the time horizon for pension investments is on the order of decades, not allowing for intervening trading is an oversimplification. To validate a one period model, the investor is either assumed to be barred from further trading, or their investment decisions are myopic. Despite its simplicity, the static mean variance framework is commonly used in applied analysis of portfolio choice. For comparison, we also present optimal solutions for a utility function with the variance penalty replaced by a shortfall penalty. Shortfall is defined as the maximum of zero and the difference between a wealth target and the realized return. The investor's utility is penalized by subtracting the expected mean square shortfall. More elaborate models are often limited in the types of constraints that can be included. [1]

For illustrative purposes a simple investment scenario is parameterized. The investor chooses between four assets: market index, bond index, cash and company stock. The small number of assets is not atypical for DC plan investors. Such plans usually offer a relatively small set of investment choices, including a few stock and bond mutual funds, a money market investment and company stock. Each asset is given typical return and volatility parameters. Let vector and matrix indices 1 to 4 correspond to market, bond, cash and company stock respectively. The parameters of the base model used throughout this paper are

$$R = \begin{bmatrix} 1.10 & 1.05 & 1.00 & 1.125 \end{bmatrix} \tag{1}$$

$$\sigma = \begin{bmatrix} 0.20 & 0.04 & 0.01 & 0.50 \end{bmatrix} \tag{2}$$

$$\rho = \begin{bmatrix} 1.000 & 0.750 & 0.058 & 0.500 \\ 0.750 & 1.000 & 0.250 & 0.550 \\ 0.058 & 0.250 & 1.000 & 0.029 \\ 0.500 & 0.550 & 0.029 & 1.000 \end{bmatrix} \tag{3}$$

where R, σ and ρ are mean asset returns, volatilities and correlations. The cash asset is virtually risk free. Returns for other assets are relative to cash. Values used are based on *ex − post* calculations of mean returns, volatilities and correlations of monthly data series obtained from Datastream. We used seventeen years of data (1985 to 2002) for the U.S. The values listed in (1a) are similar to actual values calculated for Dow stocks, the S&P 500 index as a proxy for the market, and two bond indices: Lehman brothers U.S. aggregate and U.S. Long Bond. The stock price volatility is set to two and a half

[1] See Campbell and Viceira (2002) for an extensive theoretical study of the individual investor's portfolio choice problem. For continuous time approaches to the pension investor's problem, see Rudolf and Ziemba (2002).

times that of the market, a level that is fairly high for large cap stocks but not atypical for mid-size companies (Mitchell and Utkus, 2002). The model parameters are also generally consistent with data in the literature (Dimson, Marsh and Staunton, 2002, Segall, 2001, Constantinides, 2002). The return properties for company stock are chosen to satisfy the Capital Asset Pricing Model (CAPM),

$$r_w - r_f = \frac{\rho_{wM}\sigma_w}{\sigma_M}(r_M - r_f) \tag{4}$$

where r_w, r_M and r_f are returns on own-company stock, market and risk-free rate, σ_w and σ_M are volatilities of own-company stock and market, and ρ_{wM} is correlation of returns of own-company stock with the market.

To specify a risk aversion parameter for the base case scenario, we assume that, in aggregate, investment advisors provide customers with portfolio recommendations that satisfy their needs. Professional investment advice often contradicts recommendations of economic models of portfolio choice. However, progress is being made towards reconciling practice and economic theory (Campbell and Viceira, 2002). We take a calibration approach to choosing k to reconcile portfolio weights based on our simplified model with typical investment advice. We assume an investor who is best off with a portfolio mix of 40% in bonds and 60% in the stock market index. The optimal portfolio of stocks, bonds and cash are plotted as a function of risk aversion parameter, R_A, in Figure 1a. The optimal holding of stock reaches 60% at R_A close to 8. The remaining 40% is divided between bonds and cash. Thus, R_A for the base case is set to 8.

The optimal portfolio has no company stock holdings. In a CAPM economy, this is as one would expect, since the excess return of the stock is insufficient to compensate for the undiversifiable portion of the stock risk. With no trading constraints, company stock will never be held in an employee portfolio. However, for investor's faced with trading constraints, such as the inability to short sell, company stock can appear as an optimal choice. For example, holding all other parameters constant, company stock appears as an optimal portfolio choice at low risk aversion. At a risk aversion of five, the short-selling constraint becomes binding and the optimal portfolio begins to shift to the riskier stock investment (Figure 2). However, to obtain company stock holdings above 50%, as observed in Table I, requires a risk aversion parameter below 0.5.

The expected stock return used for the base case, (1), is consistent with unconditional expectations in a CAPM type economy. However, employees of a company might have information that causes them to expect greater return from their company than is reflected by market valuation. Optimal portfolio choices are plotted as a function of expected return on company stock in Figure 2a. Company stock begins to enter the optimal portfolio as return expectations approach 20%. But the expected return must be greater than 50% for the optimal allocation to reach 50%. Recalling the standard deviation parameters, (2), we observe that this equates to a Sharpe ratio of one for company stock, which is twice the ratio for the market asset and four times that anticipated based on the CAPM relation.

Thus far we have assumed that all employee wealth is contained in the company pension plan. This assumption is reasonable considering that many North Americans save little beyond what enters their tax sheltered accounts. However, Figure 1b shows what proportion of wealth would have to be held outside the plan in order to support a 50% holding within the plan. An employee with risk aversion of

8 and 50% of their pension plan in company stock would have to have 50% of their retirement savings outside the company plan.

The effect of human capital on investment choice can be modeled as an additional risky asset in the employee's portfolio. The value of the asset is determined by assuming an expected starting annual income, i_0, and income growth rate g. The value of the asset is

$$v_{hc} = \left(i_0 \big/ \sum_{j=0}^{t-1} g^j\right)^{1/t}. \tag{5}$$

Consider an employee with twenty years to retirement and starting income equal to twenty percent of wealth (in the retirement plan). The present value of human capital would be 1.12 times wealth. For the base case scenario, we also assume a 20% income volatility and 80% correlation between income and return on company stock. Optimal asset choices are plotted as a function of income in Figure 1c, and of expected stock return in Figure 2b. In both cases, the parameter choice required to obtain high company stock holding become more extreme with inclusion of the untradeable asset. This result confirms findings of Viceira [2001], who concluded, in a continuous-time setting, that investor's with an untradeable asset tended to hold less risky portfolios.

In a mean-variance portfolio setting, high company stock holdings can only be explained by extreme values of risk aversion or expected return for company stock. These values only become more extreme once certain restrictive assumptions required for mean variance analysis are relaxed.

2 A stochastic programming model for portfolio choice

The mean-variance approach relies on distributional assumptions that need to be relaxed in order to fully study the portfolio choice problem for pension plan investors. The normal distribution does not fit stock returns well in the tails, particularly returns sampled at quarterly or greater frequency. This is especially true for individual stocks. The probability that an individual stock will experience an extreme negative event, such as bankruptcy, is greater than is predicted by a best fitting normal distribution. [2] In addition, human capital can only be included in a mean-variance model as an asset that follows the same distributional assumptions as the financial assets.

As an alternative to mean variance analysis we develop a discrete time stochastic optimization model of the employee's investment problem. The employee's concave utility is expected discounted value of terminal wealth minus a shortfall penalty. Shortfall is as defined in the previous section. Concavity of the utility function is obtained by having penalties accumulate as a convex function of shortfall. The penalty function is piecewise linear. Thus, the problem is equivalent to a large linear program for computational purposes. To obtain results comparable with the previous section, the penalty function is constructed to approximate a quadratic in the shortfall. In this manner, the expected penalty approximately equals half the variance when expected return on optimal portfolio equals the wealth target. Thus, a judicious choice of target wealth minimizes the difference between the two solutions.

[2] Longin (1996), using 105 years of data for the S& P 500 and equivalent predecessors, argues that the distribution of return outliers is best fit with a Fréchet distribution, yielding tails that are much fatter than those of normal or lognormal distributions.

The stochastic programming model is similar to that of Geyer *et al* [2002]. The model is a one period formulation. The decision variables are the purchases and sales for N assets in each scenario. The investor chooses an asset allocation at time 0, and receives investment proceeds at time 1. The problem is

$$\max E\left[\sum_{i=1}^{N} W_{i1} - \lambda c(M)\right], \tag{6}$$

where W_{it} is wealth in asset i at time t. λ is a coefficient of risk aversion, and $c(M)$ is a function of wealth shortfall at time 1, M. At time zero, the investor faces N balance constraints and a budget constraint,

$$W_{i0} - P_{i0} + S_{i0} = E_i, \qquad i = 1, \cdots, N, \tag{7}$$

$$\sum_{i=1}^{N} [P_{i0}(1+t) - S_{i0}(1-t)] = 0, \tag{8}$$

The E_i are endowments of each asset. P_i and S_i are purchases and sales respectively of asset i, and t represents transaction costs. The time 1 constraints are

$$W_{i1} = W_{i0} R_i, \qquad i = 1, \cdots, N, \tag{9}$$

$$\sum_{i=1}^{N} W_{i1} + M \geq \bar{W}_t, \tag{10}$$

where $\bar{W}_t$ is the threshold for determining wealth shortfall, and the R_i are the realized returns.

Approximation of return distributions is a significant challenge in stochastic programming. The solution of (6-10) requires a means of approximating the expectations that appear in the objective function. The usual method is to perform a discrete approximation to the integral, by replacing a continuous multivariate distribution with a discrete distribution. For multiperiod problems, the discrete distribution takes the form of a scenario tree. With T time steps and V realizations per node, the number of scenarios increases as V^T on a non-recombinant scenario tree. The number of nodes increases at the same rate. The power law relationship between number of nodes and realizations per node seriously limits feasible problem size, since computational time is proportional to number of nodes. Solution of a stochastic program effectively requires solution of a linear program at each node. As a result, even for small problems, computational restrictions limit V and T to magnitudes of order 10. Berkalaar *et al.*(2002) list some event trees used in the literature. These previous applications, each involving three to seven assets, have employed scenario trees with at most ten time steps and one hundred scenarios per node. Gondzio and Kouwenberg (2001) develop algorithms that allow them to solve problems with almost five million scenarios. They show that solutions to a seven stage asset allocation problem do not stabilize even with thirteen scenarios per node.

One method of creating scenarios is to generate V realizations of the random variables, and use these as sample points for estimating the expectation. However, less than one hundred realizations is a very crude approximation to a multi-dimensional integral. We employ two methods to partially overcome this issue. First, we employ pseudorandom sequences in place of random deviates. The random generation of scenarios is equivalent to a Monte Carlo integral approximation. Such approximations are improved significantly by the use of pseudorandom sampling (Press *et al.*, 1997). In particular, we make use of a multi-dimensional Sobol sequence to generate scenario returns (see Pennanen and Koivu for another discussion of this approach). Second, a potentially significant source of bias is eliminated by adjusting scenario returns to reflect model mean and variance. Kallberg and Ziemba (1983) demonstrate that return mean and variance plays the greatest role in determining portfolio allocations, with solutions ten time more sensitive to the mean than the variance. In stability tests, we find that thirty scenarios is the minimum required to reach a stable solution.

A serious issue arises when continuous return distributions are approximated with scenario trees: the possibility of arbitrage (Berkalaar *et al.*, 2002, Klaassen, 2002). Arbitrage occurs if a costless asset allocatio can be found that guarantees zero return in all states and that produces a profit in at least one state, or if a negative cost asset allocation can be found that produces a non-negative return in all future states. Arbitrage occurs almost certainly if the number of assets exceeds the number of return realizations. With just four assets and thirty scenarios per node, arbitrage does not affect our solutions.

Portfolio decisions for the base scenario, equation (1), are plotted in Figure 3A. The overall pattern of the solution is similar to that obtained by mean-variance (Figure 1B). Since mean-variance penalizes excess returns as well as losses, mean variance solutions for risk aversion equal to R_A, will correspond to mean-shortfall solutions with penalty parameter, $\lambda = 2R_A$. In both cases company stock disappears from the portfolio completely for risk aversions above five.

3 Portfolio choice with extreme events and job loss

A major risk factor for the employee is the possibility of a meltdown of the company stock held in their pension portfolio. Normal distribution models of stock returns place inadequate weight in distribution tails. Increased weight in the tails of the distribution has a disproportionately large negative effect on the expected utility for risk averse investors. For example, for mean-variance investors, the weight given to extreme events increases as the square of the distance of the extreme outcome from the mean.

One method of capturing the influence of extreme events on portfolio decisions is to model the distribution of stock returns using a fat tailed distribution. For example, the normal distribution could be replaced in the return model with a fat-tailed distribution. However, given the small number of discrete outcomes used to model the full multi-variate distribution, the tails of the distribution are unlikely to be sampled sufficiently to reveal any difference in the solution outcomes. This is especially true if we use pseudorandom sequences. Such sequences are designed to give a balanced sampling of the probability distribution. As a result, the early terms of the sequence are guaranteed not to sample extreme values.

To overcome the above difficulty we model the possibility of an extreme outcome by explicitly including an extreme scenario. Extreme events are returns that occur more than two standard deviations from the mean. To specify the extreme scenario, we postulate an alternative distribution function for the left tail of the distribution. Studies of extreme values of stock return distributions suggest that stock return distributions obey a power law decay. Longin [1996] and Cont [2000] suggest a decay exponent of 2.5 to 3. The implication is that stock returns have finite variance, but that higher order moments do not exist. The t-distribution follows a power law decay path in the tails. The exponent of the power law decay is equal to the t-distribution parameter. Assuming a decay exponent of n and using the t-distribution to specify the mean and probability mass of returns in the two standard deviation tail yields the extreme scenario

$$r_m^e = \int_{-\infty}^{-2} x t(x;n)/T(\text{¡}\,2;n)dx, \qquad p(r_m^e) = T(\text{¡}\,2;n),$$

where r_m^e is the extreme stock return, $t(x;n)$ and $T(x;n)$ are probability and cumulative distribution functions for the t-distribution.

Our results demonstrate no significant effect of extreme scenarios on portfolio decisions. When plotted as a function of risk aversion, the portfolio decisions closely resemble the solutions obtained without extreme events (Figure 3A). This result confirms earlier conclusions by Chopra and Ziemba (1993) who demonstrate that portfolio choice decisions are most sensitive to first and second moments of distributions.

We also employ the stochastic programming model to examine the effect of job loss on portfolio choice. The probability of job loss increases if the company runs into serious difficulties. To account for this possibility, the employee is terminated with scenario dependent probability $\gamma_t(s_t)$. Employee termination does not necessarily have to be accompanied by company default or *vice-versa*. Thus, we do not explicitly model company default. Instead, we assume that probability of termination is a non-linear function of the stock price factors, increasing rapidly as the stock price approaches zero. A logit function is used to model the probability of termination: $\gamma = 1/(1 + a\exp(\sum bX))$ where a and b are parameters and X is stock return. The probability of termination approaches 1 as the return approaches zero. Thus, the parameter, a, takes on a small value. The b set the rate at which termination probability decays as price factors increase.

We consider a scenario in which the employee receives an income, i, equal to ten percent of starting wealth. The expected income in each scenario is calculated as i multiplied by probability of job retention: 1 ¡ $logit(r; a, b)$, where r is return on company stock. Parameters, a and b are chosen to yield significant job loss properties once company stock return drops below 0.5, rapidly rising to almost certain job loss in the case of zeros return or bankruptcy (Figure 3B). We assume the employee considers loss of labour income as an addition to any shortfall. The portfolio choices are calculated for the returns parameters given in (1). The results clearly indicate a shift to a more conservative portfolio when potential loss of labour income is included in the portfolio choice problem (Figure 3C). At low levels of risk aversion, company stock holdings are replaced by holdings in the market. At higher risk aversion, the total holdings of bonds and cash are much higher than those observed when potential income loss is not included in the analysis.

4 Discussion

The litany of risk factors that recommend against company stock has led most previous studies to presume that employee investment decisions are the result of behavior that is inconsistent with rational portfolio choice. For example, employers, as plan fiduciaries, may be in a position to influence employee decisions and steer them towards company stock (Mitchell and Utkus, 2002). Employees may interpret the channeling of employer contributions into company stock as an endorsement of that investment (Mitchell and Utkus, 2002). Alternatively, employees may choose company stock arise simply because it is listed an investment option. Benartzi and Thaler (1999) have found that many DC plan investors follow some version of the $1/n$ strategy; i.e. they divide their contributions evenly across plan offerings. In addition, employees may be myopic when evaluating risk of company stock. John Hancock (2001), in a survey of DC plan participants during a period of stock market growth, reported that DC plan participants rated company stock less risky than an equity mutual fund. Other factors, such as loyalty and peer pressure considerations may also influence employee investment decisions.

Trading constraints have also been discussed as explanations for high company stock holdings. For example, many companies that match contributions to pension plans, deposit company stock. Often, an employee is restricted from trading this stock. However, the interest in this paper has been in exploring potential explanations for extremely high company stock weights such as those listed in Table I. In most cases, any minimum holding constraint for company stock is not binding. Employees hold more company stock than they have to (Mitchell and Utkus, 2002).

The results of this paper reinforce the conclusion that large holdings of company stock in pension accounts cannot be explained by traditional models of rational portfolio choice. As a result, explanation of the exceptionally high observed holdings continues to rely on behavioral explanations. The problem with behavioral explanations of company stock holdings is that they presuppose some ignorance on the part of the employee or an ability of the employer to dupe the employee. However, large holding in company stock is a phenomenon that has persisted for decades. Thus, employees would appear to have been making the same errors in their portfolio choices for a long time. One would expect the irrationality of employee choices to lessen over time as employees learn from previous actions and consequences. This leads us to suspect that there is some factor(s) that need to be included in rational choice models to explain company stock holdings. This is a topic for future research.

References

[1] Benartzi S. 2001. Excessive extrapolation and the allocation of 401(k) accounts to company stock. Journal of Finance 56: 1747-1764.

[2] Benartzi S. and R. H. Thaler. 2001. Naive diversification strategies in defined contribution saving plans. American Economic Review 91: 79-98.

[3] Berkelaar, A., H. Hoek and A. Lucas. 2002. Arbitrage and sampling uncertainty in financial stochastic programming models. Working Paper.

[4] Campbell, J. Y. and L. M. Viciera. 2001. Who should buy long-term bonds? *American Economic Review* 91: 99-127.

[5] Campbell, J. Y. and L. M. Viciera. 2002. *Strategic Asset Allocation: Portfolio Choice for Long-Term Investors*, Oxford University Press.

[6] Cont, R. 2001. Empirical properties of asset returns: stylized facts and statistical issues, *Quantitative Finance*, 1: 223-236.

[7] Constantinides, G. M. 2002. Rational Asset Prices. *Journal of Finance*, 57: 1567-1591.

[8] Dimson, E., P. Marsh and M. Staunton, 2002. *Triumph of the Optimists: 101 Years of Global Investment Returns*, Princeton University Press.

[9] Fleten, S.-E., K. Hoyland and S.W. Wallace. 2002. The performance of stochastic dynamic and fixed mix portfolio models. *European Journal of Operational Research* 140: 37-49.

[10] Geyer, A., W. Herold, K. Kontriner, W. T. Ziemba. 2002. The Innovest Austrian pension fund financial planning model InnoALM. Working Paper.

[11] Kallberg, J. G. and W. T. Ziemba. 1983. Comparison of alternative utility functions in portfolio selection problems. *Management Science* 29: 1257-1276.

[12] Longin, F. M. 1996. The asymptotic distribution of extreme stock market returns. *Journal of Business* 69: 383-408.

[13] Mankiw, N.G. and S. P. Zeldes. 1991. The consumption of stockholders and non-stockholders. *Journal of Financial Economics* 7: 265-296.

[14] Meulbroek, L. 2002. Company stock in pension plans: how costly is it?. Working Paper.

[15] Mitchell, O. S. and S. P. Utkus. 2002. Company stock and retirement plan diversification. Working Paper.

[16] Pennanen, T. and M. Koivu. 2002. Integration quadratures in discretization of stochastic programs. Stochastic Programming E-Print Series.

[17] Press W. H., S. A. Teukolsky, W. T. Vetterling, B. P. Flannery. 1997. *Numerical Recipes in C* (Cambridge University Press, Cambridge).

[18] Rudolf, M. and W. T. Ziemba. 2002. Intertemporal Surplus Management. To appear in *Journal of Economic Dynamics and Control.*

[19] Siegel, J. J., and P. Bernstein. 2002. *Stocks for the Long Run : The Definitive Guide to Financial Market Returns and Long-Term Investment Strategies*, McGraw-Hill.

[20] Ziemba, W.T. and J.M. Mulvey, eds. 1998. *Worldwide Asset and Liability Management* (Cambridge University Press, Cambridge).

Table 1: **Table I:** Percentage of DC plan assets in company stock (*The Economist*, December 15, 2001, p.60).

Company	Company stock percentage	Share price performance 2001, %	2002, %
Proctor & Gamble	94.7	-2.2	11.5
Pfizer	85.5	-12.3	-22.0
Coca Cola	81.5	-25.1	73.0
General Electric	77.4	-23.3	-37.4
Enron	57.7	-99.1	-85.4
Texas Instruments	75.7	-34.5	-46.1
McDonald's	74.3	-22.1	-39.3
Ford	57.0	-28.9	-38.3
Qwest	53.0	-69.7	-64.6
AOL Time Warner	52.0	-8.1	-59.2

Figure 1: Results of mean-variance model of portfolio choice. Properties of the optimal portfolio are plotted as a function of risk aversion (A-B) and expected return on company stock (C). Shaded regions indicate portfolio weights (left scale). The line represents the expected return on the optimal portfolio (right scale). Diamonds indicate values of independent variable for which calculations were performed. Plots are interpolated between calculated points. Results for the three asset case, with no company stock, are plotted in (A). Results for the four asset case are plotted in (B) and (C).

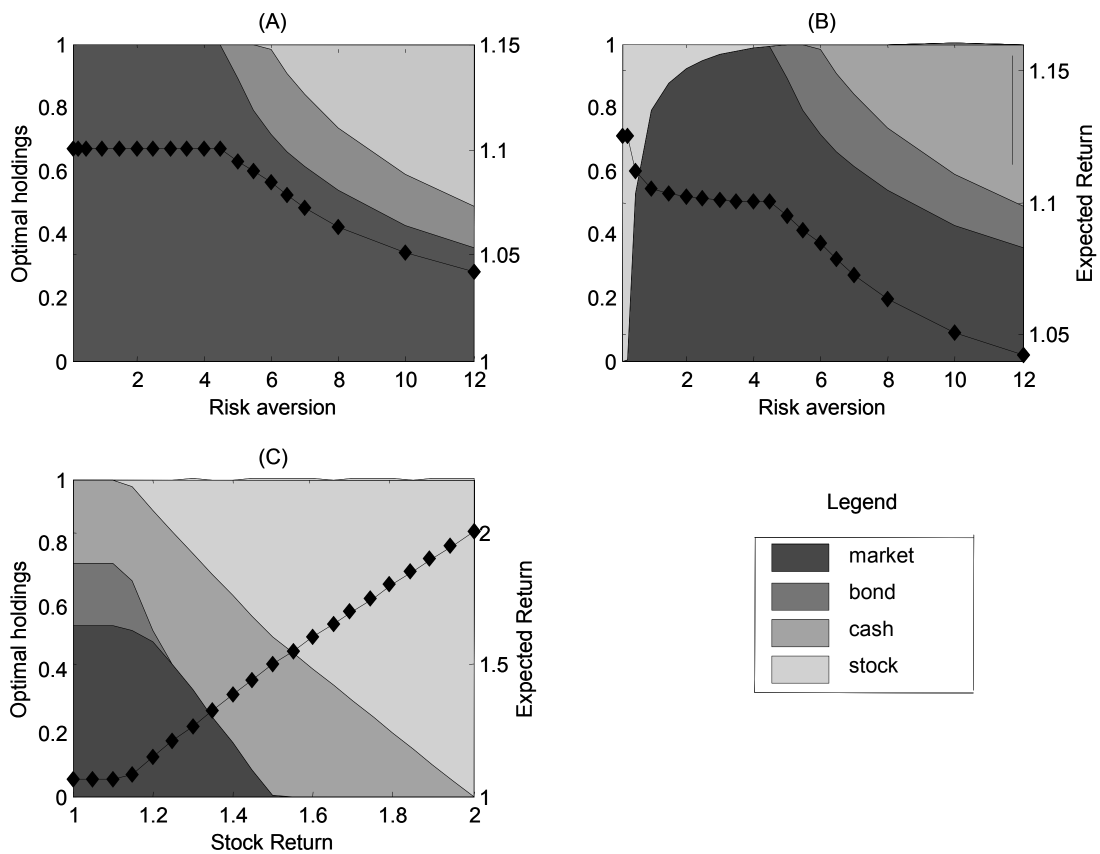

Figure 2: Results of mean-variance model when human capital is modeled as an untradeable asset. Optimal portfolio properties are plotted as a function of risk aversion (A) and expected return on company stock (B). Shaded regions indicate portfolio weights (left scale). The line represents the expected return on the optimal portfolio (right scale). Diamonds indicate values of independent variable for which calculations were performed. Plots are interpolated between calculated points. Results for the three asset case, with no company stock, are plotted in (A). Results for the four asset case are plotted in (B) and (C).

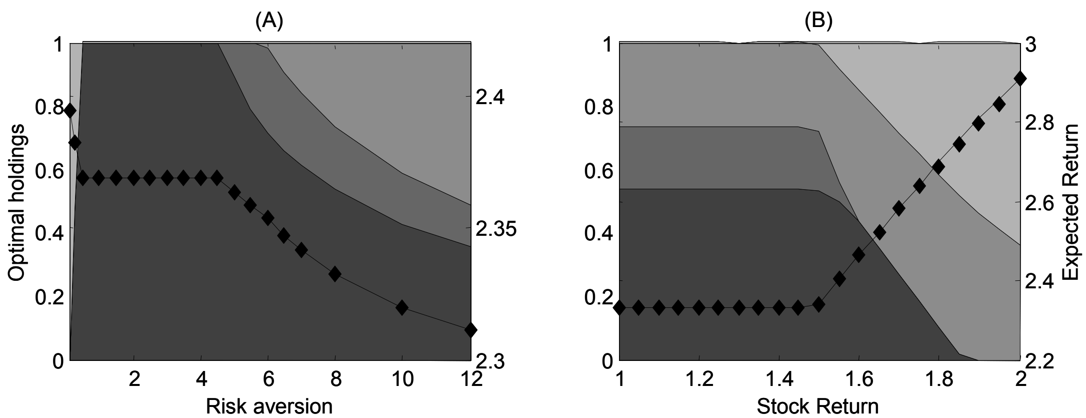

Figure 3: NEED TO FIX THIS CAPTION Solution of employee's problem formulated as stochastic program. Portfolio weights (shaded regions/right scale) and expected return on the optimal portfolio (line/right scale) are plotted as a function of the risk aversion parameter, λ. The plots are interpolated between λ values indicated by diamonds.

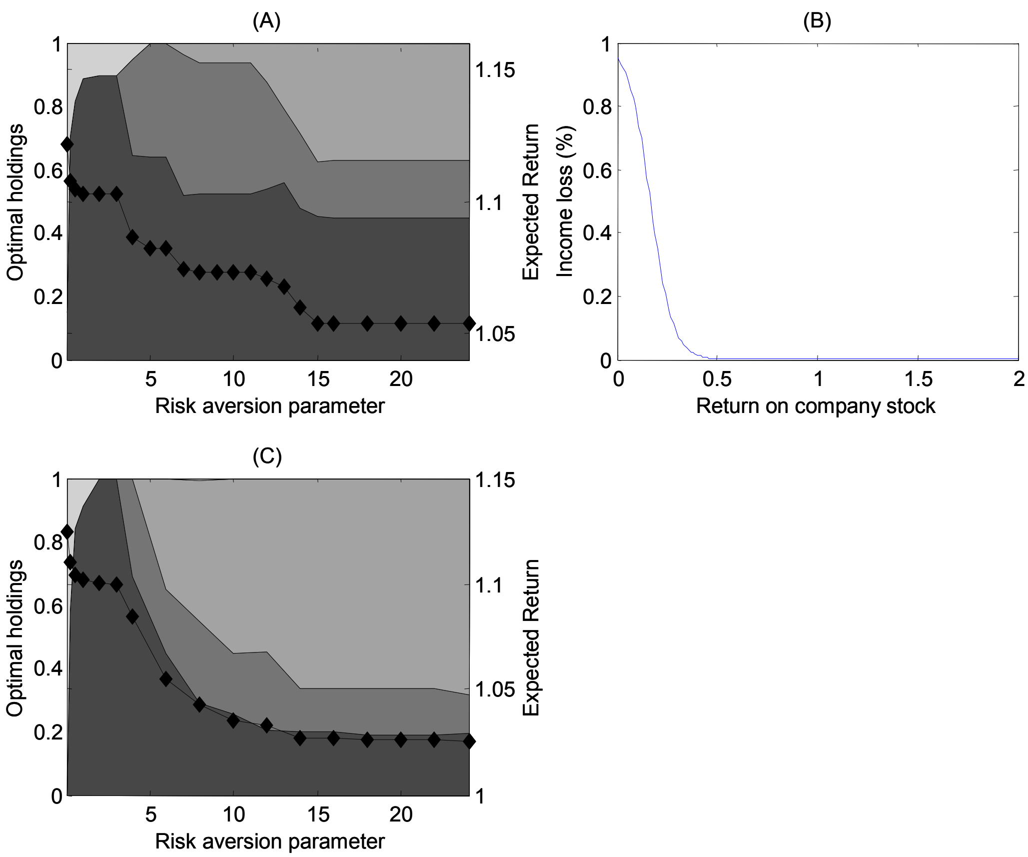

Figure 2: As in Figure1, but with company stock included as fourth asset in portfolio.

Figure 3: As in Figure 2, but with optimal portfolio weights and expected return plotted *versus* expected return on company stock.

Figure 4: As in Figure 2, but with an extra, untradeable asset included in the portfolio.

Figure 5: As in Figure 4, but with optimal portfolio weights and expected return plotted *versus* expected return on company stock.

Figure 6: Solution of employee's problem formulated as stochastic program. Portfolio weights (shaded regions/right scale) and expected return on the optimal portfolio (line/right scale) are plotted as a function of the risk aversion parameter, λ. The plots are interpolated between λ values indicated by diamonds.

Figure 7: Expected loss of income as a function of return on company stock. Income loss is modeled as a logit function of stock return.

Figure 8: As in Figure 6, but with scenario outcomes adjusted to reflect expected income loss.